NREL/TP-440-6628 • UC Category: 1210 • DE94011853

The National Wind Technology Center

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Prepared for
Windpower 1994
May 9–13, 1994
Minneapolis, Minnesota

NREL

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393
A national laboratory of the U.S. Department of Energy
Managed by Midwest Research Institute
for the U.S. Department of Energy
under contract No. DE-AC36-83CH10093

Prepared under Task No. WE437440

July 1994

Printed in the United States of America

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THE NATIONAL WIND TECHNOLOGY CENTER

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History

Wind energy research began at the Rocky Flats test site in 1976 when Rockwell International subcontracted with the Energy Research and Development Administration (ERDA). The Rocky Flats Plant was competitively selected from a number of ERDA facilities primarily because it experienced high instantaneous winds and provided a large, clear land area. By 1977, several small wind turbines were in place. During the facility's peak of operation, in 1979-1980, researchers were testing as many as 23 small wind turbines of various configurations, including commercially available machines and prototype turbines developed under subcontract to Rocky Flats. Facilities also included 8-kW, 40-kW, and 225-kW dynamometers; a variable-speed test bed; a wind/hybrid test facility; a controlled velocity test facility (in Pueblo, Colorado); a modal test facility, and a multimegawatt switchgear facility. The main laboratory building was dedicated in July 1981 and was operated by the Rocky Flats Plant until 1984, when the Solar Energy Research Institute (SERI) and Rocky Flats wind energy programs were merged and transferred to SERI. SERI and now the National Renewable Energy Laboratory (NREL) continued to conduct wind turbine system component tests after 1987, when most program personnel were moved to the Denver West Office Park in Golden and site ownership was transferred back to Rocky Flats. The "Combined Experiment" test bed was installed and began operation in 1988, and the NREL structural test facility began operation in 1990. In 1993, the site's operation was officially transferred to the DOE Golden Field Office that oversees NREL. This move was in anticipation of NREL's renovation and reoccupation of the facility in 1994.

Planned Development of the Industrial User Facility

During the next two years, the NWTC will be completely upgraded to a state-of-the-art research facility. We are currently remodeling existing buildings and plan to build a new, 10,000-ft^2 Industrial User Facility (IUF).

The IUF will be the center for collaborative activities with the wind industry. The building will include office space for industry researchers working with wind program technical staff. The IUF will house experimental laboratories, computer facilities for analytical work, and space for assembling components and turbines for atmospheric testing. The IUF is intended to be a flexible facility designed for light industrial activities, and can house a number of different experiments and activities simultaneously.

Plans also call for an Advanced Research Turbine (ART) facility consisting of two turbines. These machines can be fitted with various components for testing. Nearby test pads will also be available for testing entire machines under the Advanced Wind Turbine (AWT) program. Figure 1 shows the planned layout of the NWTC.

Our laboratory structural testing capabilities include fatigue testing, static strength testing, photo-elastic stress analysis, and modal testing. These capabilities will expand with the addition of the IUF, which will house a blade test platform capable of accommodating blades up to 28 m long. A dynamometer facility at the NWTC will enable us to test low-speed generators and even complete drive trains (including gear boxes). Moreover, we will be able to use the dynamometer as a wind turbine simulator, testing electrical, mechanical, and control systems. Structures code development will also continue. As wind turbines are designed to be lighter and more flexible, the need to accurately predict and understand system dynamic interactions will increase. This will require continued validation and refinement of the Automatic Dynamic Analysis of Mechanical Systems (ADAMS) and FAST structural dynamic codes.

A hybrid power test facility planned for the NWTC will allow us to test commercial hybrid power systems that are near market ready. This user-oriented facility will be used to develop and evaluate new commercial hybrid systems, and to train foreign nationals in hybrid system operation.

A totally new area planned for the NWTC involves certification test capabilities. Such testing capabilities will include power performance and acoustics and may eventually cover dynamic loads, grid compatibility, and component testing such as blades and drive trains.

Advanced Research Turbine (ART) Facility

The planned ART facility will consist of two test bed machines with versatile designs that can be configured for a number of purposes:

- Advanced component development testing, which wind businesses are unlikely to undertake because of risk, cost, or complexity

- Full system research testing to improve our fundamental understanding of wind turbine technology.

Two side-by-side test machines are required to discriminate between small 5%–10% differences in performance and loading while testing in turbulent atmospheric winds.

The ART test beds will be used for component and research testing, so cost-effective power production is not a driving design issue. The structures will not be optimally designed for specific configurations but will be rugged and heavy-duty to enable them to handle a wide variety of rotors and power trains, which will be exposed to diverse operating and environmental conditions. Therefore, important features will be versatility, component interchangeability, and structural integrity. The baseline turbines will be identically designed to provide the following features and capabilities:

- Ability to accommodate different rotors, including two-bladed and three-bladed
- Operation in either an upwind or downwind configuration

- A main frame designed to enable various combinations of drive train components to be interchanged and tested
- Operation in fixed, active, or free yaw
- A pitch actuator system with full-span blade pitch control
- An approximately 25-m, free-standing tubular tower
- A versatile control system to allow special test modes of operation.

Currently, plans call for one of the test bed turbines to be of a three-bladed, upwind, active-yaw, rigid-hub configuration. The second will have a two-bladed, downwind, free-yaw configuration. Various tests are planned to study advanced airfoil performance and optimize rotor design.

Structural Testing

NREL's structural test facility has been operating since 1990 (Figure 2). It is used primarily for structural testing of full-scale wind turbine blades for NREL's subcontractors and wind industry partners. The present capabilities include fatigue testing, ultimate static strength testing, and several nondestructive techniques such as photoelastic stress analysis. Fatigue tests currently use a closed-loop servo-hydraulic system to apply cyclic loads to blades up to 20 m (66 ft) long. Under repeated loading, accelerated fatigue failures help wind turbine blade designers evaluate design assumptions, manufacturing techniques, and complex failure modes under normal and extreme operating loads.

Static tests reveal the failure mode under maximum strength loading and are valuable in evaluating the less frequent, hurricane-limit load conditions. Photoelastic techniques have helped designers visualize strain distributions over the complex surfaces of composite blades under static loading. Acoustic emissions tests, performed in cooperation with Sandia National Laboratories, were used as an early warning for structural failures to help pinpoint "hot spots" in the blade. Although still very experimental, these acoustic measurements may give blade designers a fast, nondestructive method for structural evaluation.

Planned upgrades at the NWTC include the new IUF, which will be partially dedicated to structural testing. This new facility will accommodate larger blades (up to 28 m) under both static and fatigue loading. New fatigue testing equipment will be added to more accurately and quickly simulate the actual wind loading in the laboratory. With the new IUF addition, blade fatigue testing will be available at two separate buildings at the NWTC. Wind turbine blade designers will be encouraged to use the new facilities under cooperative research and development agreements (CRADAS). In the future, these facilities may also be used to carry out testing for wind turbine blade certification.

Modal Testing

Modal testing is a technique to experimentally determine structural dynamic characteristics (mode shapes and natural frequencies) and has been used on structures as small as computer disk drives and as large as megawatt-scale wind turbines. Modal testing will be an important part of the NWTC's structural testing program. The modal test facility at the NWTC incorporates the most advanced test equipment available. All equipment is assembled in a portable data van and hydraulic trailer so that tests can be quickly transported and conducted at the turbine site or in a structural test facility. Software and hardware have been optimized to quickly produce detailed results. As a result, printed mode shapes and natural frequencies can be assembled into a preliminary report on site. This facility will be used to test most of the prototype advanced wind turbines (AWTs), as well as blades prior to fatigue testing and, possibly, turbines under certification testing.

Figure 3 shows a schematic diagram of a typical modal test setup and illustrates how all the major pieces of test equipment are used to excite the structure and record the dynamic response.

Structures Code Development

A major goal of the federal wind energy program is to rapidly develop and validate structural models for determining loads and responses for a wide variety of wind turbine configurations operating under extreme conditions. As wind turbines become lighter and more flexible, comprehensive systems dynamics codes are needed to predict and understand complex interactions.

Figure 4 compares predicted root edge-wise bending moment and test data for a two-bladed teetering-hub turbine. This turbine exhibits a complex system interaction involving blade root edge-wise bending and nacelle and tower-top pitch.

Until recently, no structural dynamics codes were capable of analyzing such a system interaction because the codes had limited degrees of freedom and restrictive assumptions. Now, the development and validation of models using the ADAMS software has demonstrated the ability to predict these complex interactions. ADAMS can be used to predict system interactions and the turbine design changes needed to minimize such interactions.

Other useful tools are the Oregon State University (OSU) FAST2 and FAST3 codes (for two- and three-bladed rotors). These codes use a limited number of degrees of freedom to model the turbine. Although the codes do run faster than ADAMS and can be used to quickly run turbulence loads for fatigue life estimation, they are restricted as to the types of machine configurations and degrees of freedom that can be modeled. Still, they are useful for industry members who do not need the more complex capabilities of ADAMS. We are currently adding new degrees of freedom to FAST2 and FAST3, based on our ADAMS modeling experience.

With the design of lighter and more flexible machines, the need to accurately predict and understand such system interactions will only increase. We will continue validation and refinement of the ADAMS and FAST codes to ensure that these more complex machines can be accurately modeled.

NREL Dynamometer Capability

The major dynamometer components available at NWTC are two direct current (DC) motors rated at 100 and 300 horsepower [HP] and an alternating current (AC) induction motor rated at 25 HP. All three can be operated at variable speed. The two DC motors are driven by a VIP-type phase-controlled converter (AC-DC). The AC induction machine is driven by a variable-frequency, pulse width modulated (PWM) inverter (AC-DC-AC). The inverter is rated at 40 HP and has a regenerative feature that allows power to be returned to the utility. The AC induction machine can be operated as a variable-speed motor or a variable-speed generator. Currently, two concatenated gear boxes are available to connect the prime mover (motor) to the device under test (generator). Thus, different gear ratios can be implemented to test complete drive trains, including gear boxes. Torque, speed, voltage, current, watt and var transducers are available to measure the desired quantities. The NREL dynamometer is shown in Figure 5. NREL's dynamometer capabilities are being considered for enhancement as part of the IUF.

The dynamometer will not only be used to determine the static characteristics of new generating systems. More importantly, it will be operated as a wind turbine simulator. Besides controlling it manually, we also plan to program the dynamometer with input wind speed and the parameters of the wind turbine. The dynamometer can be used to test the following:

- Electrical systems (electric machine parameters; power quality of converters, including voltage/current harmonics and EMC; reliability and response of system protection on fault and abnormal conditions; and the efficiency of the systems)
- Control systems (stability, transient response, and control algorithms)
- Mechanical systems (load stress, gear box, vibrations, and audible noise).

Other equipment currently available to support the dynamometer includes three separate load banks (R, L and C). The load banks are three phase and capable of absorbing 300 kVA each. There is a diesel gen-set rated at 208/416 V, 60 kVA allowing us to simulate parallel operation into a mini grid. A second inverter rated at 50 kW and a synchronous generator rated at 240/480 V and 100 kW are also in the inventory.

Hybrid Power Test Facility

A Hybrid Power Test Facility is planned for the NWTC, and it will focus on testing commercially available hybrid power systems. This facility is one element of a larger NREL activity to assist U.S. industry in developing new technology and applications and markets for small wind and hybrid power systems. To this end, NREL is also developing hybrid power system performance models and providing international technical assistance.

The key objectives of the Hybrid Power Test Facility will be to

- Install and test small wind and hybrid power systems that are nearly market-ready
- Develop and test, in collaboration with industry, new approaches that will improve performance and cost effectiveness
- Provide a system development user facility for U.S. industry and a training facility for foreign nationals.

We are designing the facility with an emphasis on versatility and flexibility, providing both real and simulated wind and PV energy sources. The simulated renewable energy sources will allow repeatable testing and testing under controlled combinations of solar and wind resources. A controllable load bank with both resistive and inductive components will be used to simulate village loads up to 80 or 100 kW. The heart of the facility will be a distribution panel (see schematic in Figure 6) that will allow the facility to be reconfigured quickly. This panel will permit the connection of any of the source or load simulators to any of the hybrid power systems on site. When fully developed, the facility will be capable of simultaneously testing two or more hybrid power systems. Test parameters will include overall energy delivery and fuel consumption, power quality, response to transients, and response to simulated mechanical and electrical failures.

We have developed an initial concept for the facility. Detailed designs will be completed this summer. Facility construction may begin late in 1994 as part of the overall renovation of the NWTC. It is anticipated that two or three power systems could be under test during 1995.

Certification Test Capability Support

To support U.S. wind turbine and component manufacturers, NREL plans to develop certification test capabilities at the NWTC that would meet the requirements of other countries. Certification of wind equipment is not actually needed for installation; however, type approval certificates are required to participate in many subsidy programs, and wind turbine manufacturers are increasingly using equipment "type approval" or certification (as well as ISO-9000 registration of quality systems) as marketing tools. Initial test capabilities will include power performance testing and acoustic noise testing. Additional capabilities will include dynamic loads testing, grid compatibility testing, and component testing (including blades and drive trains). Tests of small and large wind turbines will be conducted at the NWTC and at field installations in the United States. Component testing will be performed at the NWTC using the structural testing facility and power laboratory. Such tests would result in confidential certification test reports that meet the requirements of a specified certification agent (or agents).

Cooperative Mechanisms

Industry members can currently develop cooperative projects with NREL through Cooperative Research and Development Agreements (CRADAs) and competitively awarded NREL research and development subcontracts. With the renovation of the NWTC, NREL will be developing additional ways for wind businesses to take advantage of the facilities and capabilities discussed in this paper.

Acknowledgements

The authors would like to thank Erik Nelsen, Sandy Butterfield, Palmer Carlin, Larry Flowers, Jim Green, Darrell Dodge, Alan Laxson, Ed Muljadi, Walt Musial, Rich Osgood, Dave Simms, and Alan Wright. These NREL employees contributed significantly to this paper.

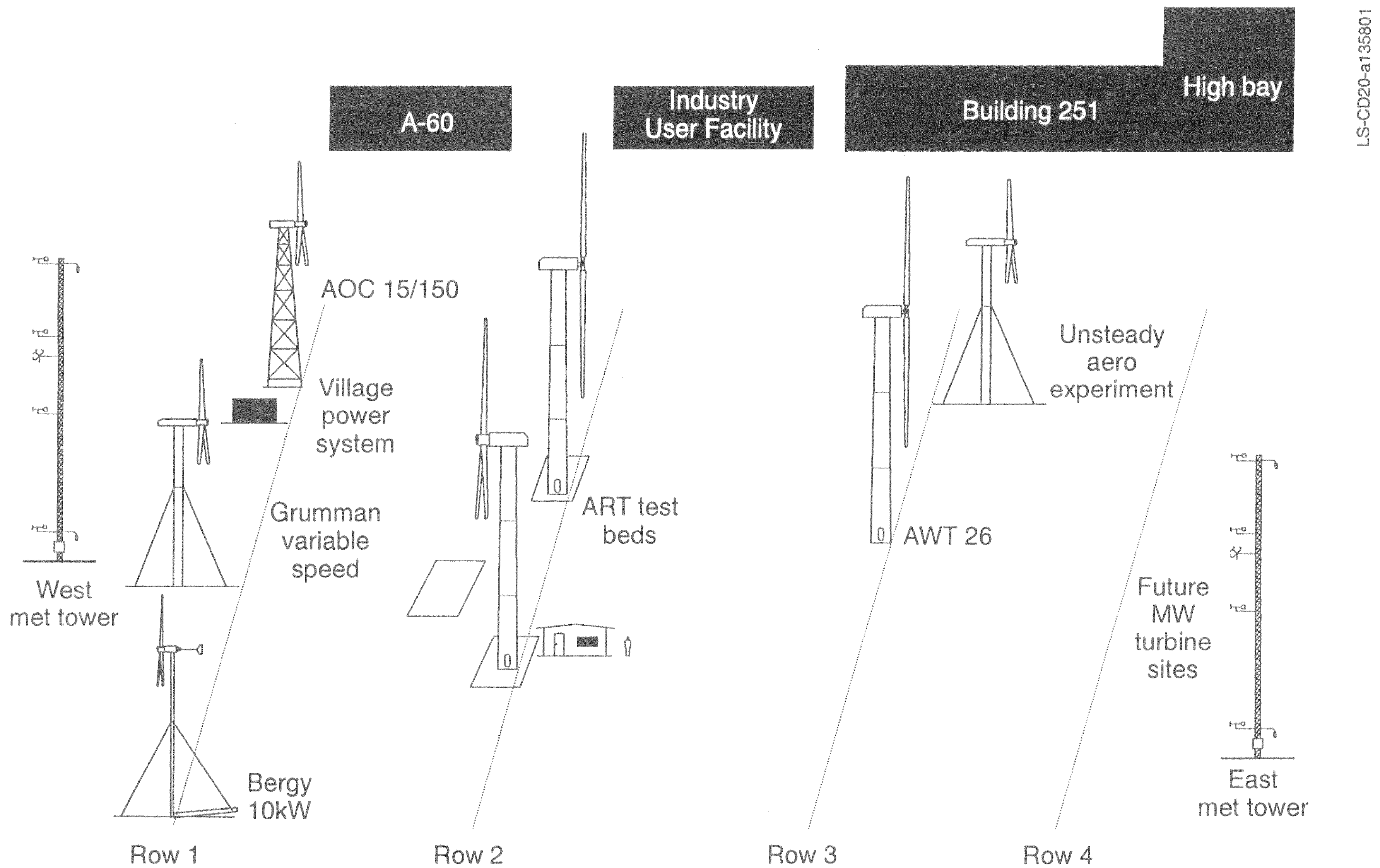

Figure 1. Planned layout of the NWTC, circa 1996

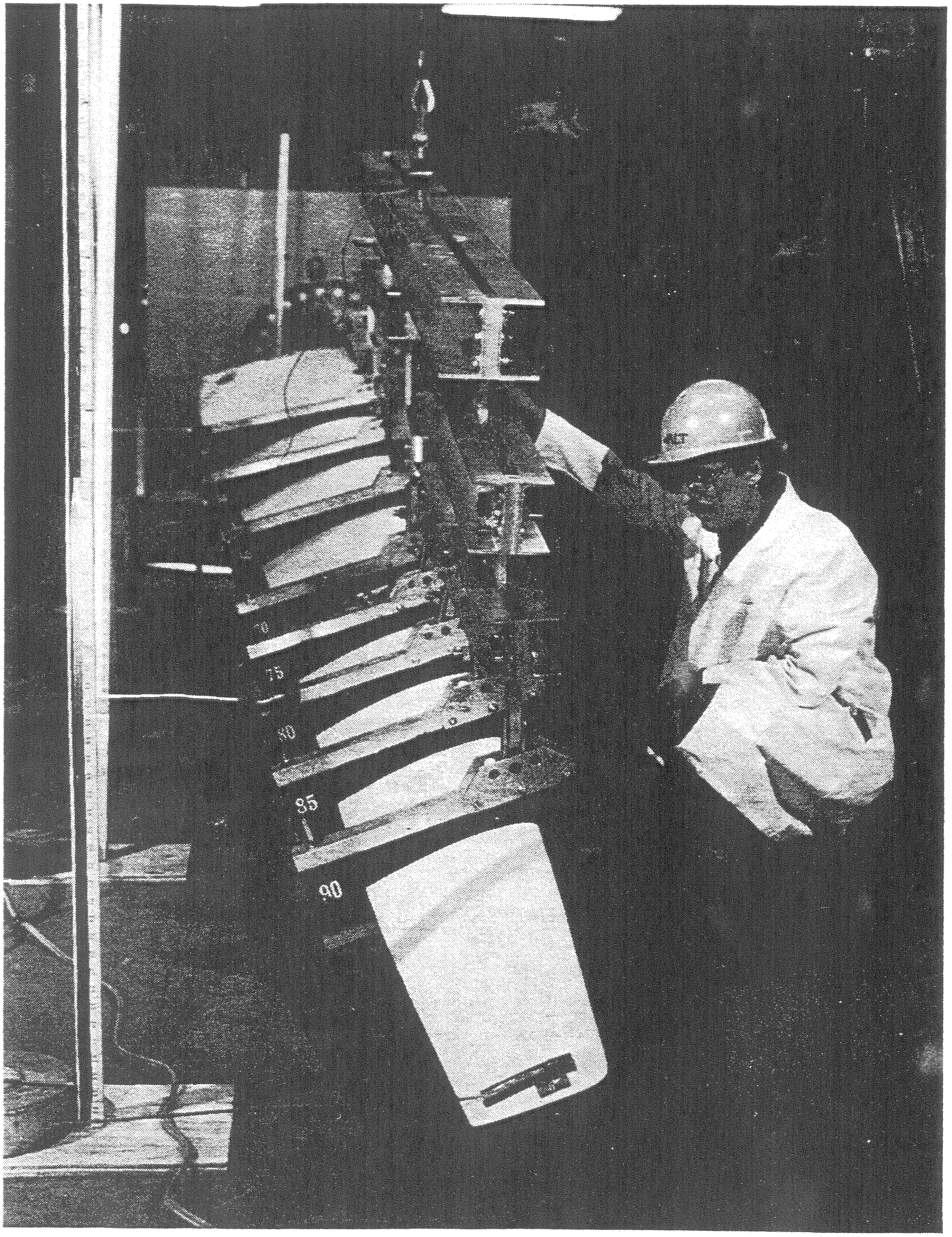

Figure 2. Structural testing at the NWTC

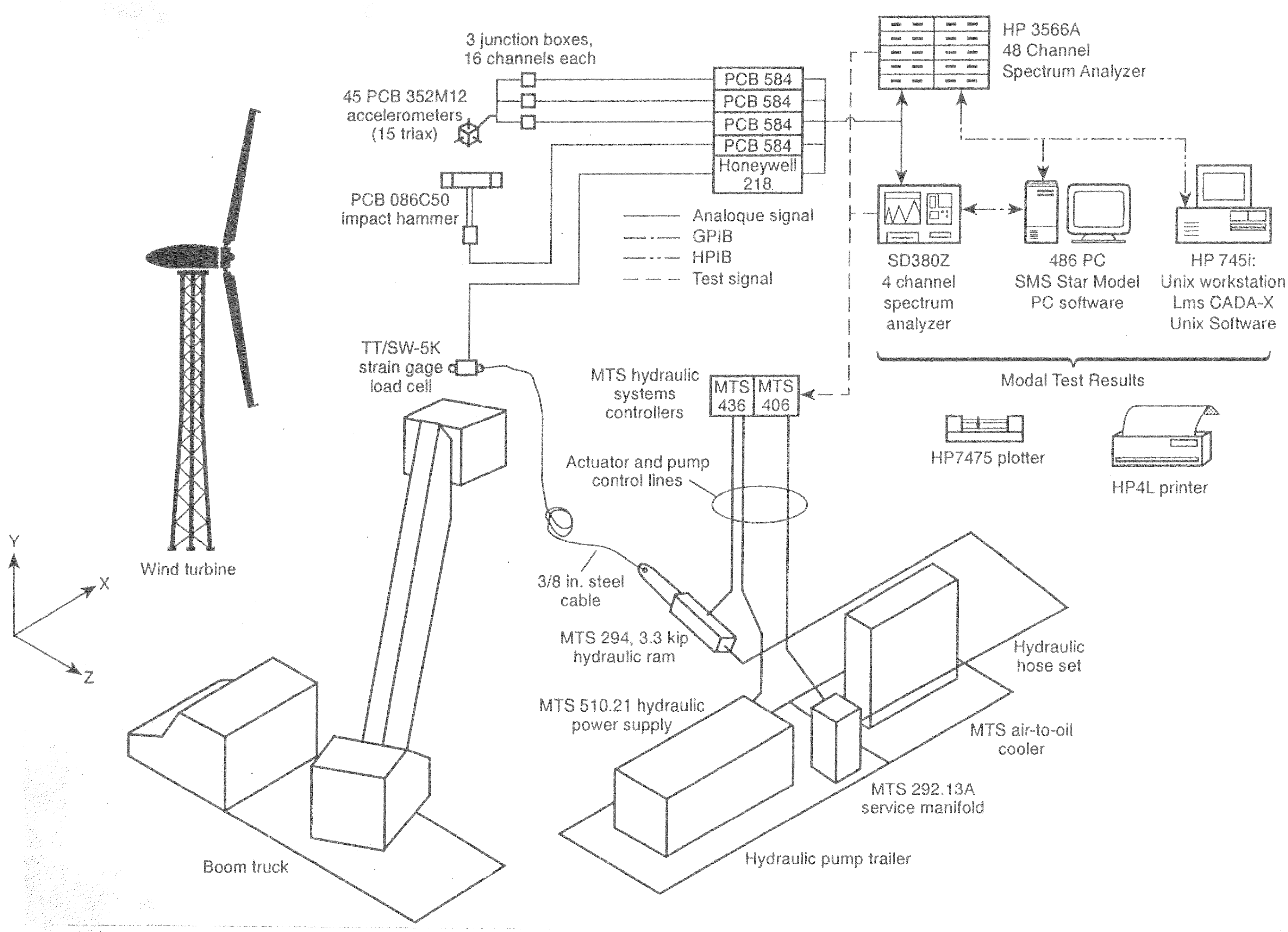

Figure 3. Full system modal test equipment setup

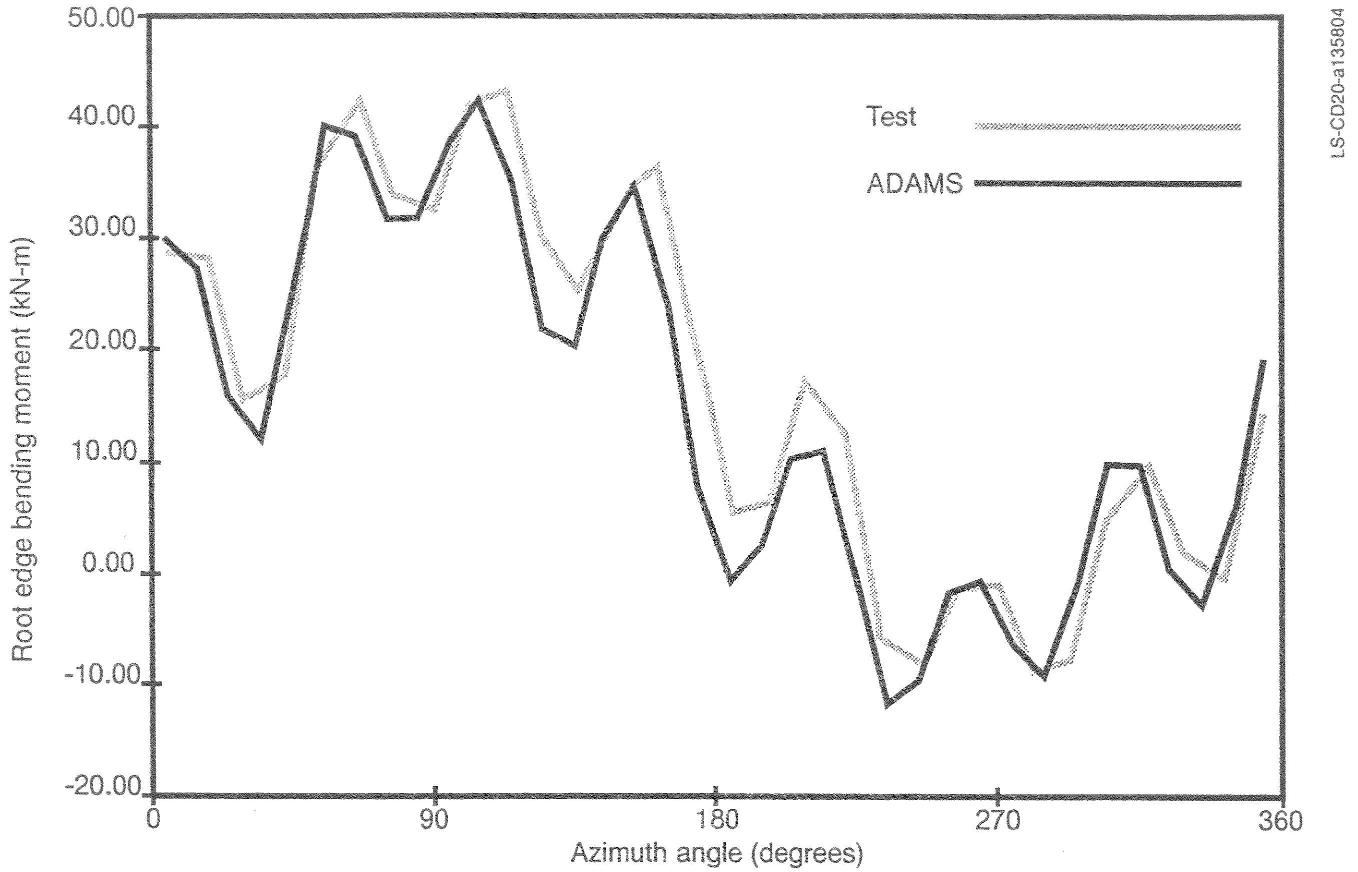

Figure 4. Predicted root edge-wise bending moment and test data for a two-bladed teetering-hub turbine being developed under the AWT Program

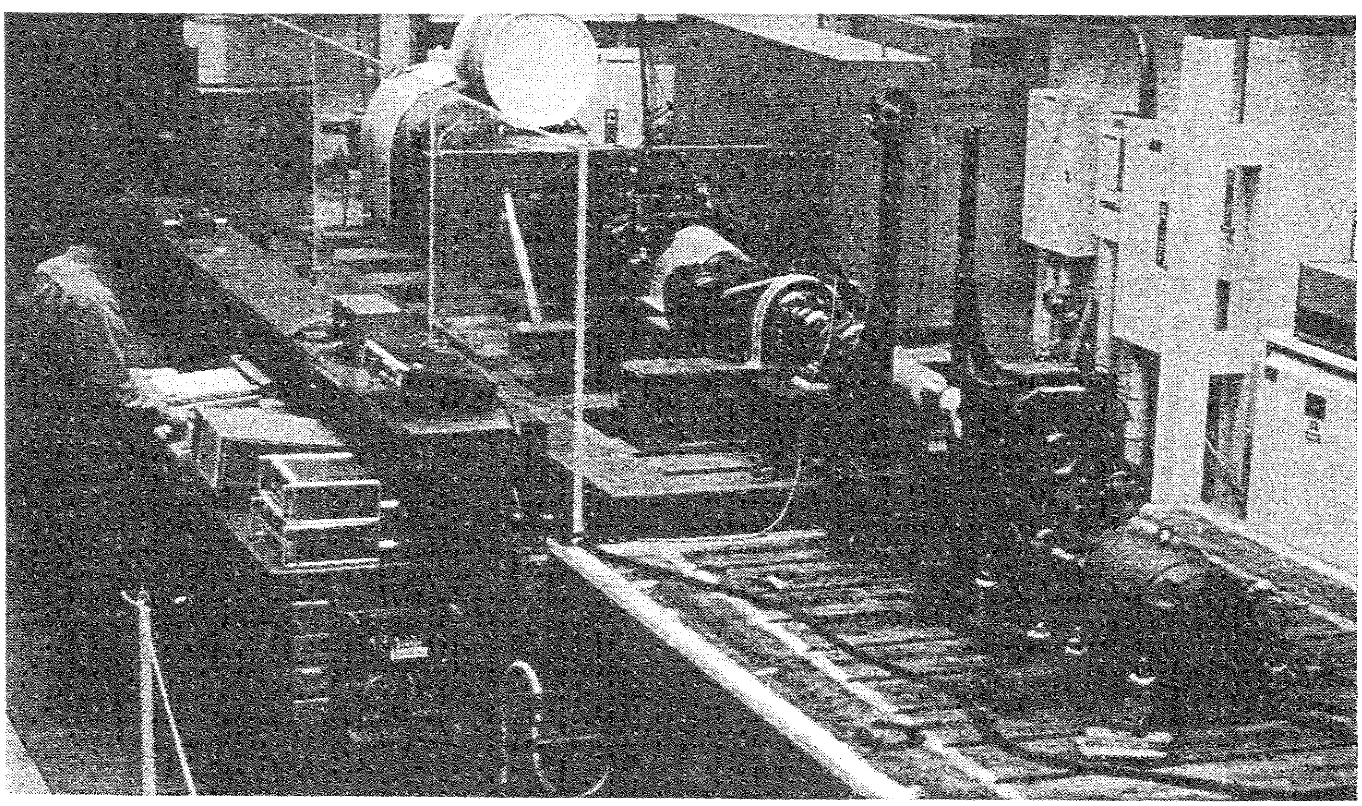

Figure 5. The dynamometer will be used as a wind turbine simulator.

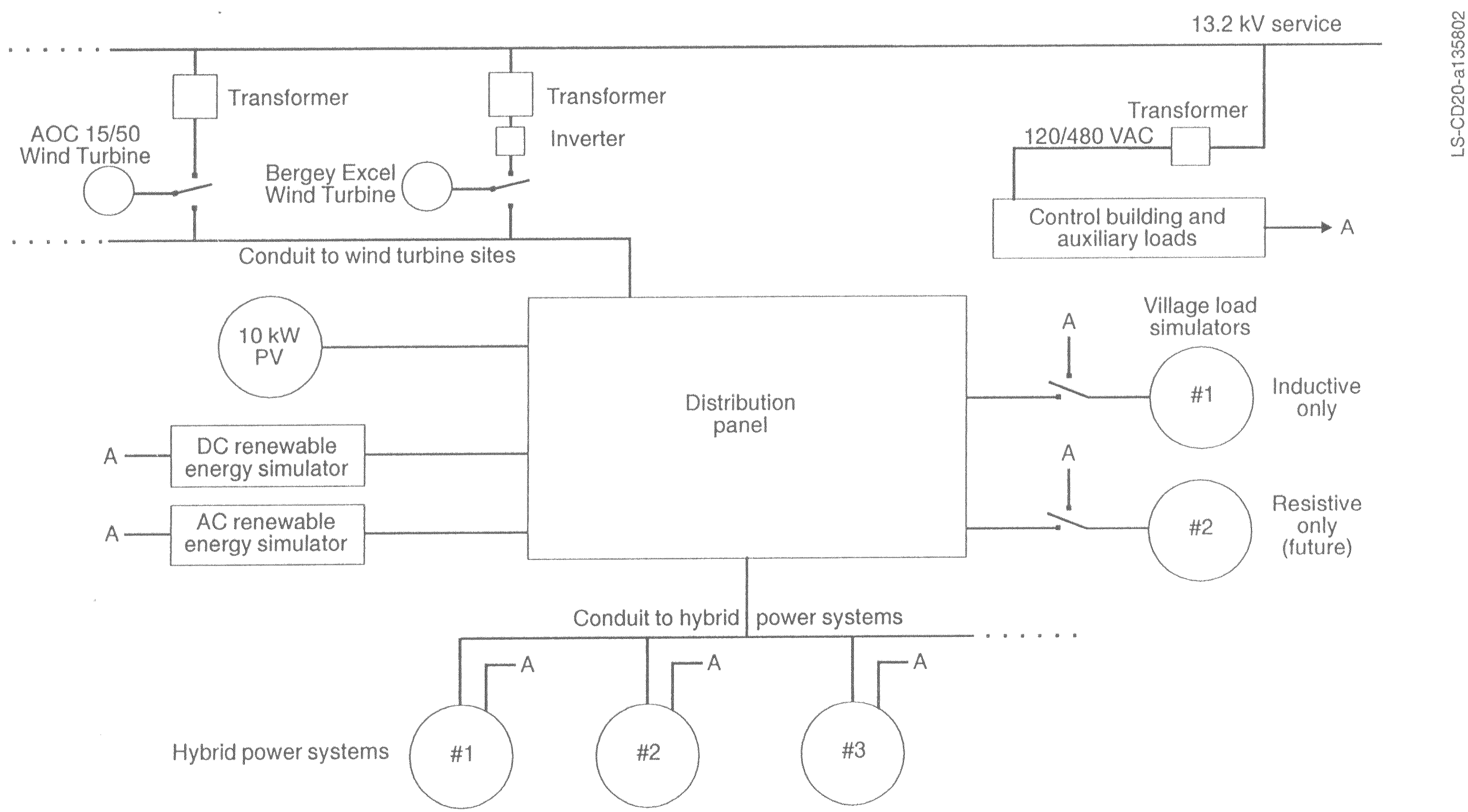

Figure 6. The hybrid power test facility planned for the NWTC